

Geomatics-Based Approach for Assessing the Roll of Public Transportation Projects in Enhancing Urban Environment

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Abstract

Urban transportation is a critical component of urban sustainability due to its vital role as an integral part of city infrastructure, as well as its influence on environmental quality and public health. In rapidly growing urban areas like Riyadh, Kingdom of Saudi Arabia (KSA), the increasing reliance on motorized vehicles has led to elevated levels of air pollution and associated health risks. In response, the Royal Commission for Riyadh City (RCRC) launched a series of public transportation mega-projects under the King Abdulaziz Project for Riyadh Public Transport, aiming to reduce traffic congestion, improve mobility, and mitigate environmental degradation. This paper is intended to investigate the effectiveness of urban planning in enhancing the urban environment by examining the impact of Riyadh's new metro on air quality using remotely sensed satellite data. For this purpose, a geomatics-based approach was adopted employing satellite-based air quality observations with geographic information system (GIS) techniques for acquiring and analyzing air pollution parameters including Carbon Monoxide (CO), Sulfur Dioxide (SO₂), and the Ultraviolet Aerosol Index (UVAI) before (January-March 2019) and after (January-March 2025) the implementation of the public transport projects. The results revealed that while aerosol levels (UVAI) increased in Riyadh by 2025, likely due to urban growth and natural dust storms, carbon monoxide (CO) and sulfur dioxide (SO₂) levels declined, indicating improved air quality. These reductions were the most notable in districts served by the Riyadh Metro's green, blue, and purple lines. Moreover, significant air quality improvements were noted in central and western areas, while some eastern districts have been experiencing an increasing trend of the considered pollutants. These findings highlight the effectiveness of Riyadh's public transport projects in reducing emissions, aligning with Saudi Vision 2030, and offer a model for sustainable urban development in other cities.

Keywords

Urban Planning, Air Quality, Riyadh Metro, Public Transportation, Remote Sensing

1. Introduction

Urban transport systems consist of varied modes such as road transport, railways, subways, etc. Road transport modes, which are the main mode of urban transportation system, play a crucial role in supporting quality of urban life through ensuring high levels of mobility. However, as it relies mainly on motorized vehicles, road transport is a significant and increasing source of a variety of air pollutants including carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) (Cunningham et al., 2001). Continued expansion of urban areas and subsequent increase in travel distances, which means an increase in the use of motorized vehicles (Kiribou et al., 2025). This, in turn, implies air pollution and deteriorating quality of urban life, at local level, and increasing greenhouse gases at global level. Moreover, road transport modes in urban areas are usually associated with high risk to road accidents. In this context, it was reported that road traffic crashes which are the leading cause of death for children and young adults aged 5 - 29 years, result in 1.19 million deaths each year globally (WHO, 2025).

In this respect, planning for urban transport systems can assist in fostering healthy and sustainable cities (Thondoo et al., 2020) through reducing traffic congestion, improving mobility and accessibility, ensuring equity and social inclusion, and sustaining air quality. Usually, attaining these objectives entails reducing dependence on private cars and promoting public transportation development that aim eventually to improve urban air quality (Bi et al., 2024; Gwilliam et al., 2004).

Extensive previous research has examined the linkages between road transportation and air quality. This can be attributed to the significant environmental, health, and socioeconomic implications of such linkages. Some of these previous studies assessed the impacts of road transport on air quality in urban areas (Tafidis et al., 2024; Guo et al., 2020; Sun et al., 2019; Cunningham et al., 2001). For example, it was argued that increasing road traffic volume induces air pollution in China's mega cities, where 80% of CO emissions and 40% of NO_x emissions come from road traffic (Sun et al., 2019). Other studies evaluated the risks associated with road transport to health of urban population (Khreis et al., 2024; Vorko-Jović et al., 2006). Meanwhile, a number of studies have explored the potential for reducing air pollution from urban transport (Kiribou et al., 2025; Bi et al., 2024; Thondoo et al., 2020; Zheng et al., 2019; Gwilliam et al., 2004). These studies emphasized the role of public transport projects in reducing air pollution in urban areas. for example, it was reported that introducing subways projects in urban

areas lead usually to significant reduction in carbon monoxide pollution (Zheng et al., 2019). Similarly, it was argued that increasing transportation infrastructure investment can contribute largely to improving air quality in urban areas (Guo et al., 2020).

A previous study on ambient air quality in Riyadh city revealed that different parts of the city have varied levels of air pollution. For example, while the south-eastern districts of Riyadh city experience the highest PM₁₀ and CO pollution levels and lowest SO₂ pollution (Alharbi et al., 2014). The need for public transport system in Riyadh city was necessitated by the need to reduce high dependence on private cars and associated air pollution (Alotaibi & Potoglou, 2018). For this purpose, the Royal Commission for Riyadh City (RCRC) has inaugurated a number of public transport mega projects including Riyadh Metro Project in addition to bus network is fully integrated with the metro network. Moreover, based on the Saudi Vision 2030, billions of dollars were allocated to rehabilitate the infrastructures and sidewalks to support the national transformation to sustainable mobility (Sultan et al., 2021). These projects serve as the cornerstone of Riyadh's Public Transportation Network and represent a key addition to the capital's mobility infrastructure (RCRC, 2025). This paper intends to use remotely sensed data on air quality to examine the improvement effect of public transportation projects undertaken by Royal Commission for Riyadh City.

Case Study

Riyadh city is Saudi Arabia's capital and central financial hub that has been developed rapidly and became a metropolis covering a total area of 1600 km² (Sultan et al., 2021; Alotaibi & Potoglou, 2018). In 2022, the total population of Riyadh city was estimated to be about 8.5 million (City Population, 2025).

Within the Royal Commission for Riyadh City's ambitious city plan, The King Abdulaziz Project for Riyadh Public Transport is intended to equip Riyadh with public transport that will provide all groups of the Riyadh population with suitable public transport services to address the current and future mobility needs in the city (Figure 1). The project, which is intended to minimize traffic congestion and vehicle emissions, involves building, operating, and developing a world-class rapid transport network for Riyadh, providing comfortable, affordable, and time-saving mobility options for all citizens throughout the city. The project will be of great benefit to the traffic flow, economy, society, and environment in Riyadh. The public transport network will create an interconnected city with six metro lines with a total length of 176 km, 85 metro stations, 80 bus routes, 2860 bus stops and 842 buses.

The Metro Project is the backbone of the public transport network in Riyadh, capable of transporting 3.6 million passengers per day. Also, the project involves the establishment of bus network that is fully integrated with the metro network, connecting the districts of Riyadh with the business and commercial centers. The bus network, with the capacity to transport over 500,000 passengers per day, will serve as a main means of transportation within residential districts. Accordingly,

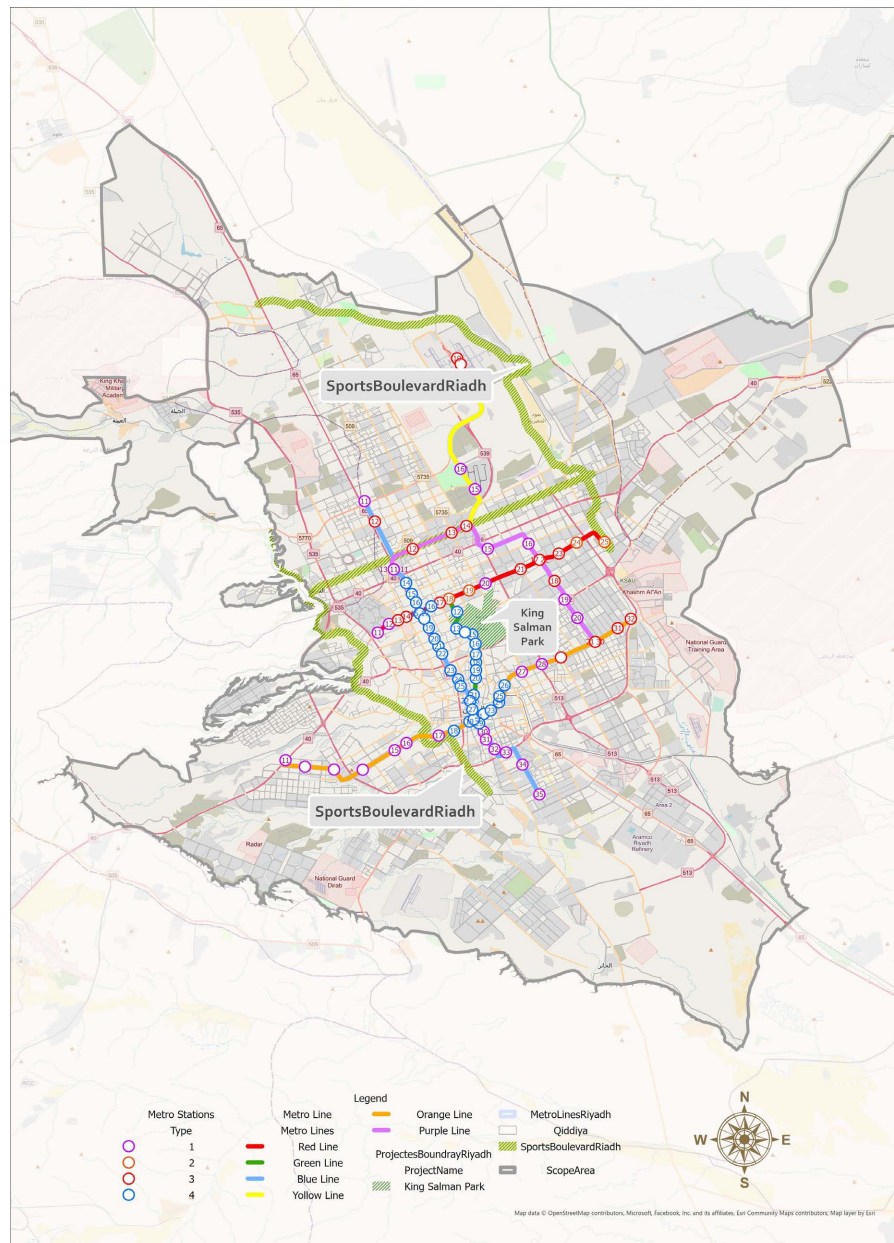


Figure 1. Riyadh metro project.

The King Abdulaziz Project for Riyadh Public Transport with its Metro and bus network components, provides a clean and reliable alternative to traditional vehicles, which can significantly reduce carbon emissions, thereby mitigating the urban heat island effect and fostering a healthier environment for all (RCRC, 2025).

2. Methodology

To examine the improvement effect of public transportation projects undertaken in Riyadh City, a methodology of three main steps was applied including data collection, data preparation, and spatio-temporal analysis (Figure 2).

- **Collecting data:** This step involves collecting data on The King Abdulaziz Pro-

ject for Riyadh Public Transport from Royal Commission for Riyadh City portal (RCRC, 2025). The acquired data were employed in characterizing the project and identifying the spatial and temporal scales of the project.

Additionally, satellite-based observations of air quality parameters were acquired for two periods: before and after the construction and operation of the Riyadh Public Transport Project. To ensure a high degree of comparability, the first period was selected from January 1 to March 31, 2019, before the COVID-19 pandemic and associated lockdown. Meanwhile, the second period was selected from January 1 to March 31, 2025 to represent the period after the construction and operation of the metro. For this purpose, Google Earth Engine, which is an internet-based platform that provides satellite imagery and cloud-based computing algorithms (Gorelick et al., 2017), was employed to download such datasets. The data on air quality parameters involves dataset involved data on CO, NO₂ and SO₂ column number density measured in the unit of mol/m² and UVAI, which is unitless.

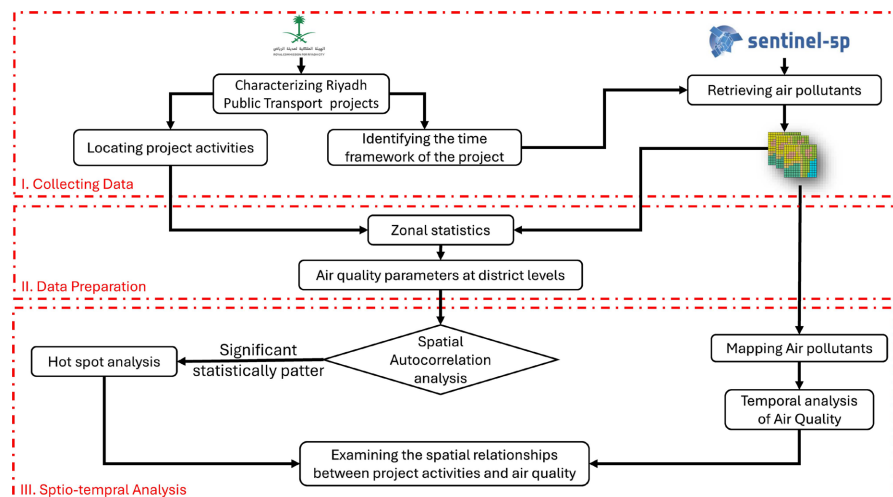


Figure 2. Methodology for examining the improvement effect of public transportation projects in Riyadh City.

It should be noted that the measurements of air pollutants in mol/m² as a proxy for air pollution may be considered a poor representation of human exposure as the vertical distribution of the pollutant is disregarded. Nevertheless, using air pollution measurements in mol/m² is useful in monitoring and comparing pollutant load at both spatial and temporal scales.

- **Data preparation:** This step comprises estimating the mean value of each air quality parameters during the at district level calculated through Zonal Statistics Tool and Spatial Join Tool. Accordingly, the change rate in the value of air quality parameters between the two study periods, before and after Riyadh Metro project, was estimated at each district of Riyadh city, where those districts that experience improvement in air quality will have negative value and vice versa.

- **Spatio-temporal analysis:** This step involves temporal analysis to identify the trends of the considered air quality parameters in various parts of Riyadh city during the period 2019-2025. For this purpose, multiple Gaussian distribution graphs were employed to track trends of the considered air quality parameters. Meanwhile, spatial analysis involves mapping various considered air quality parameters in the two study periods. Moreover, Spatial analysis involves evaluating the spatial pattern of changes in air quality parameters through applying Spatial Autocorrelation (Moran's I index). This is followed by delineating the main hot and cold spots through hot spot analysis and examining the spatial relationship between the delineated hot and cold spots, and the extent of Riyadh Metro project. Finally, the spatial relationships between the changes in air quality parameters and new public transportation projects in Riyadh city.

3. Results and Discussion

Ultraviolet Aerosol Index (UVAI) is a satellite-derived measure used to detect tiny particles like dust, smoke, and ash (aerosols) in the atmosphere. Generally, positive values of UVAI indicate the presence of smoke, dust, volcanic ash. Meanwhile, negative or near-zero values of UVAI suggest clear skies. Generally, it was noted that aerosol index values in Riyadh city have increased in 2025 compared to 2019, where the range of Aerosol index increased from -0.169 to 0.542 mol/m² in 2019 to 0.0659 to 0.754 mol/m² in 2025 indicating a higher presence of UV-absorbing aerosols such as dust or pollution. The central parts of the city, where metro lines intersect, have a higher Aerosol index in both years, but the intensity increases in 2025. Meanwhile, peripheral parts of the city (especially northwest and southeast) show relatively lower Aerosol index in both years, with slightly expanded zones of low values in 2025 (Figure 3). Metro corridors, particularly the Blue, Green, Red, and Yellow Lines, pass through areas of higher values of Aerosol index (Figure 3).

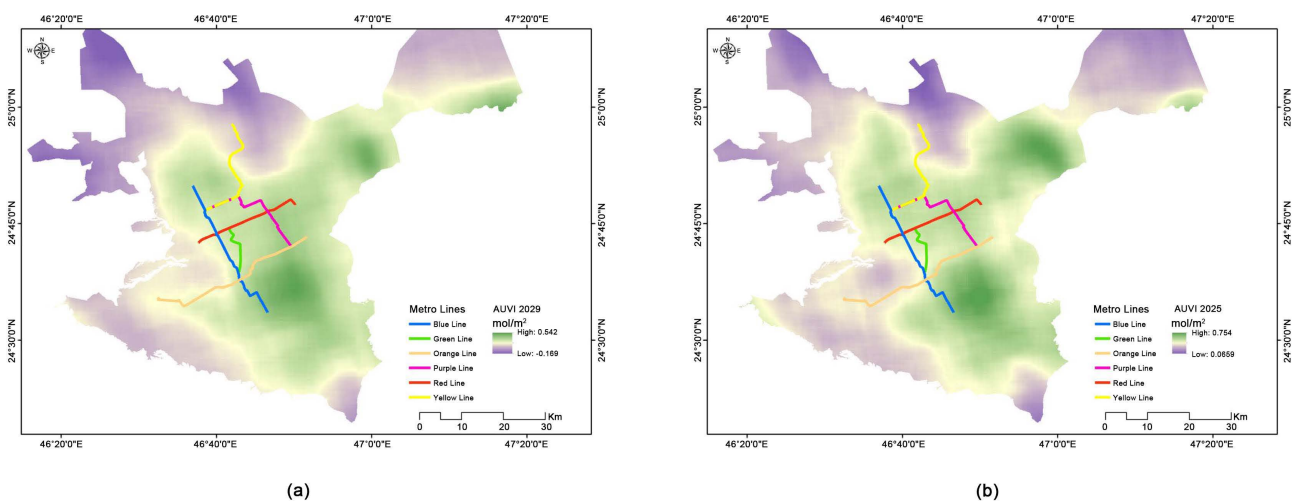


Figure 3. Levels of Aerosol index in Riyadh city in 2019 and 2025.

This may hint at urban influence (emissions, infrastructure development) contributing to UV-altering aerosol presence. The comparison suggests an intensification of aerosol index during the period 2019–2025 may be driven by urban development projects such as King Salman Park. However, it should be noted that such an increasing trend of aerosol index over time in arid regions can be linked to natural-driven factors including for example Increased frequency and intensity of dust storm and dominance of dry conditions that usually amplify aerosol mobilization.

Compared to 2019, CO levels in the central, northwestern and the southern parts of the city shrunk in 2025, which may suggest improved air quality. For example, the maximum CO level decreased from 0.0348 mol/m^3 in 2019 to 0.0339 mol/m^3 in 2025. Meanwhile, the minimum CO levels decreased from 0.0322 mol/m^3 in 2019 to 0.0312 mol/m^3 in 2025, indicating overall air quality improvement (Figure 4). Such reduced CO levels can be attributed to the establishment of the Riyadh Metro project by 2025, as public transport could replace private vehicle use, and thus reduce emissions.

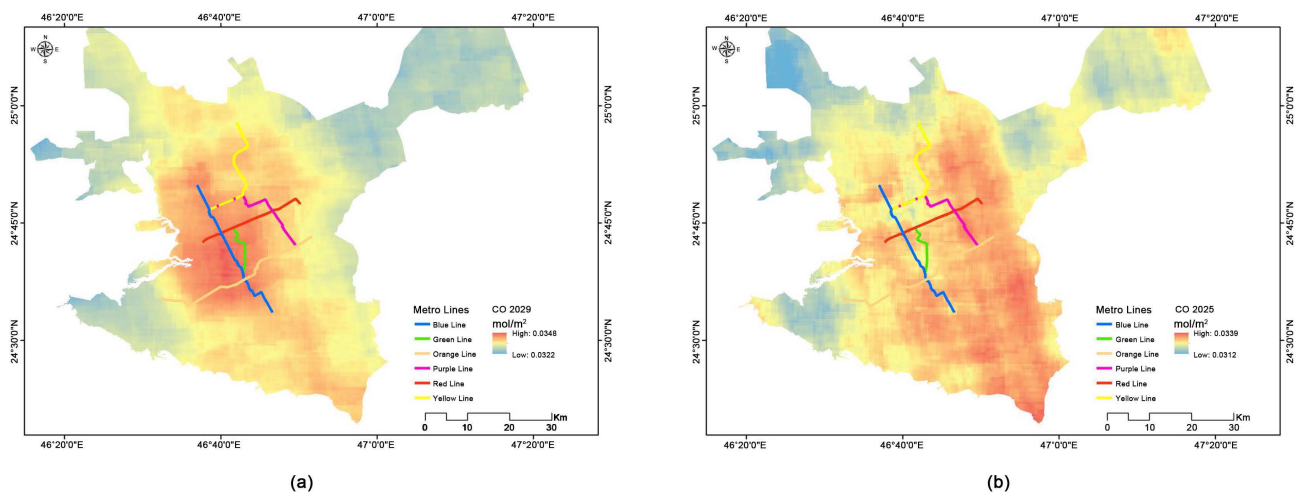


Figure 4. Levels of CO concentration (mol/m^3) in Riyadh city in 2019 and 2025.

In 2019, different parts of Riyadh city have experienced varied levels of SO_2 , where the southern and southeastern parts of the city had Higher SO_2 concentrations, central zones had moderate levels, while some northern areas had relatively lower concentrations. Moreover, a noticeable reduction was noted in the spatial extent of those parts that have high SO_2 levels, especially in the southern and central regions (Figure 5). This may indicate improved air quality that can be explained by the potential role of metro system that has become fully operational since January 2025. This, in turn, may lead to reduced reliance on cars can lead to decreased fossil fuel combustion, a major source of SO_2 emissions.

To examine such increasing trend of aerosol index, the probability density function (PDF) of the UVAI, CO and SO_2 for the years 2019 and 2025 were plotted. The graph shows a marked shift in the UVAI distribution from 2019 to 2025,

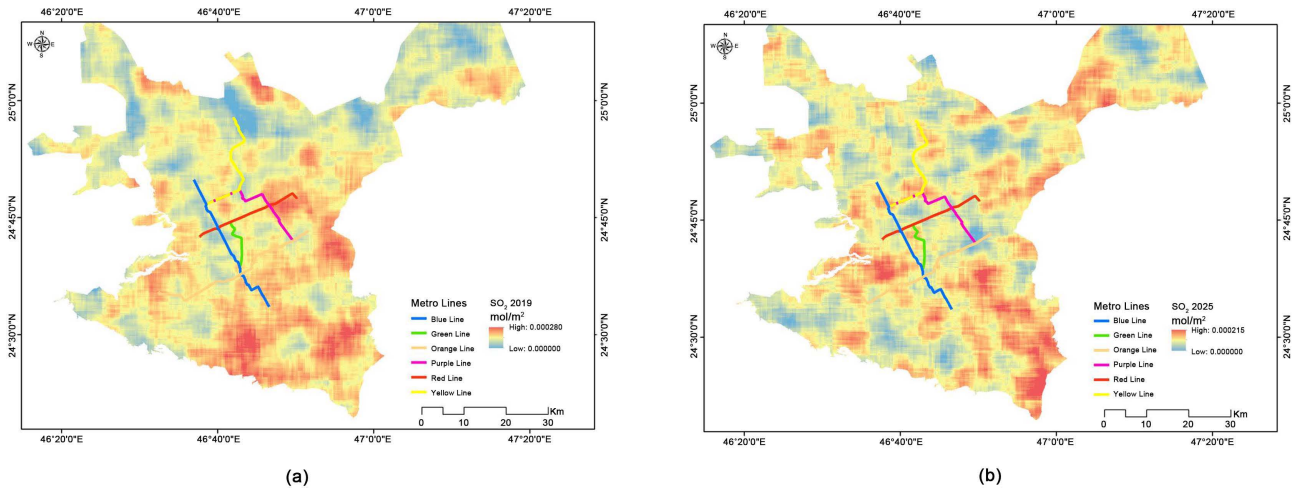


Figure 5. Levels of SO₂ concentration (mol/m²) in Riyadh city in 2019 and 2025.

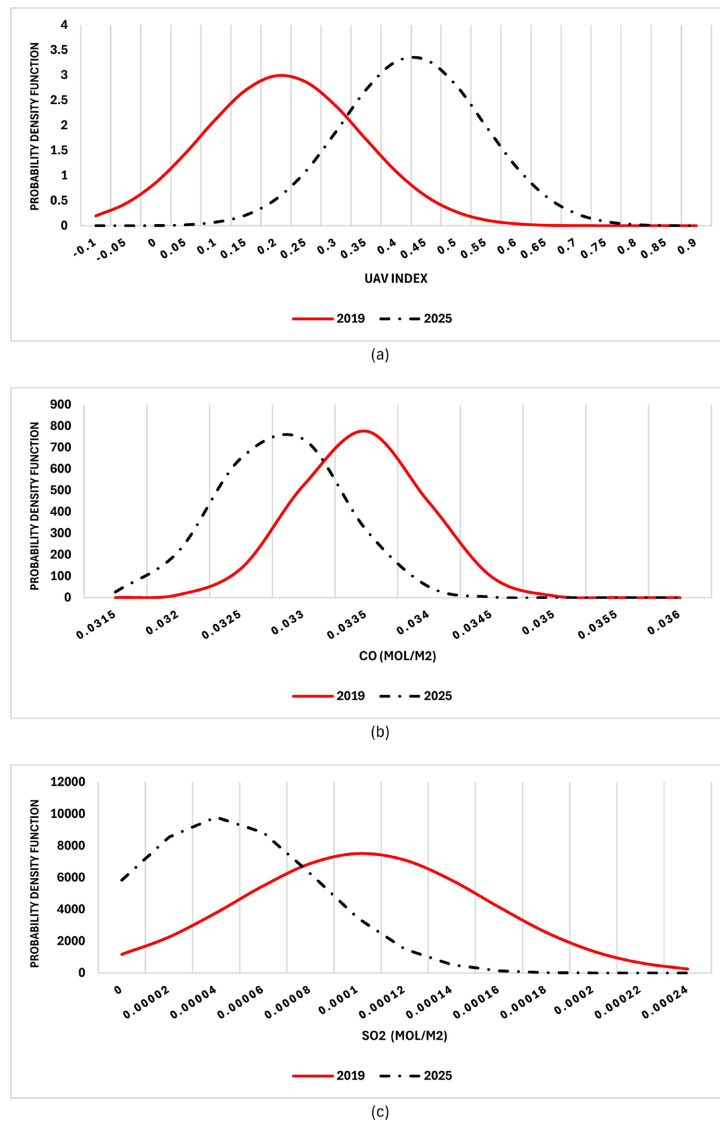


Figure 6. Gaussian distribution of UAVI, CO and SO₂ in 2025 compared to 2019.

moving to higher and more consistent values (Figure 6(a)). Meanwhile, a decline in CO was noticed during the same period indicating improvements in air quality. SO₂ level concentrations were noticed (Figure 6(b)). Similarly, there is a clear shift of the distribution of SO₂ to the left, meaning that overall air quality has improved in 2025 with a left-skewed curve, indicating a shift towards lower SO₂ concentrations and the tail is shorter, showing fewer high-concentration occurrences (Figure 6(c)).

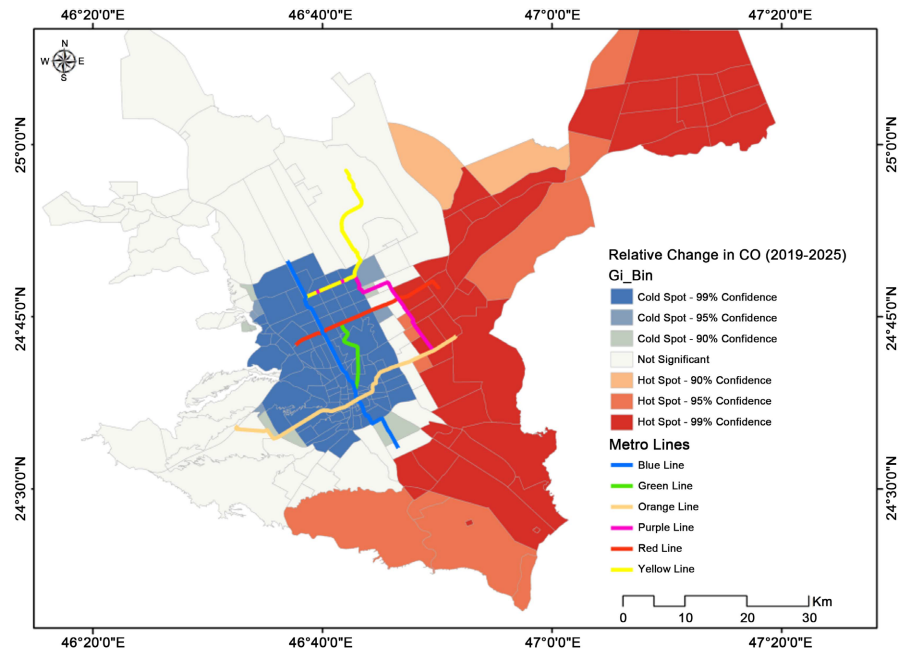
To evaluate the distribution pattern of changes in air quality parameters at district level, Spatial Autocorrelation analysis (*Moran's index*) was performed. The results revealed that the changes in UVAI during the period 2019-2025 were found to be randomly distributed across Riyadh districts. This is highlighted by Moran's Index, which had a very small value (−0.0009), along with a relatively low z-score (0.3079) and a *p*-value greater than 0.75, indicating the result is not statistically significant. Meanwhile, the spatial distribution of changes in CO and SO₂ was found to be more spatially clustered-recording a relatively high Moran's index (0.655 for CO and 0.1786 for SO₂), which are statistically significant at the 99% confidence level ($p < 0.01$) (Table 1).

Table 1. Results of spatial autocorrelation analysis.

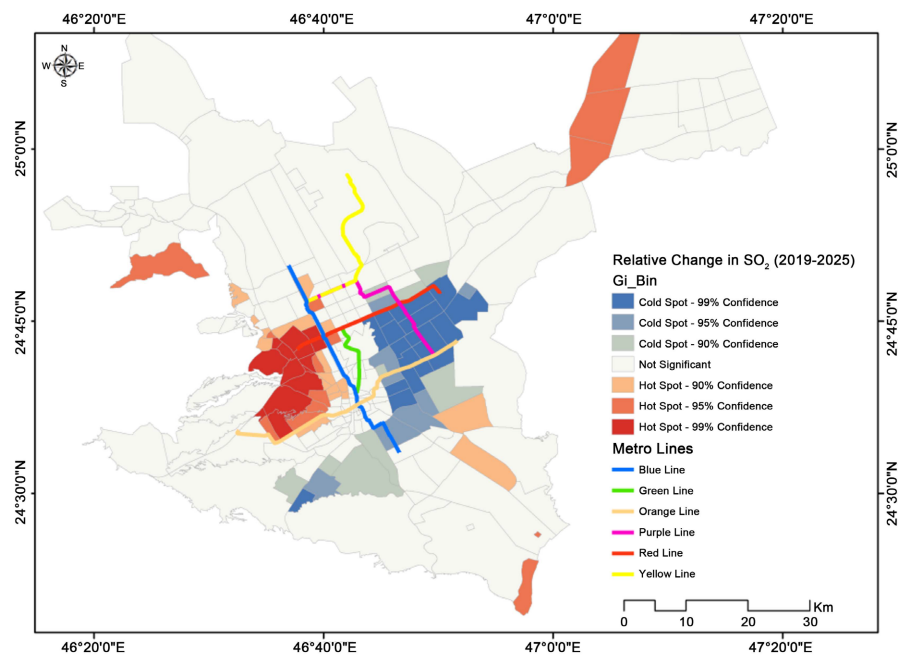
Parameters	Moran's index	Z-score	<i>P</i> value
UVAI	−0.000901	0.307932	0.76
CO	0.655152	33.468397	<0.01
SO ₂	0.178692	9.351294	<0.01

The results of Hot Spot analysis for relative changes in CO at district level during the period 2019-2025 revealed a cold spot in the central and western districts of Riyadh city, which are served by green, blue, and purple metro lines. This means that these districts have been experiencing significant reductions in CO levels during the period 2019-2025. This, in turn, indicates effective emission reduction possibly due to increased public transport usage or other mitigation efforts. Meanwhile, the eastern and southeastern districts of the city had a hot spot indicating that these districts have been experiencing increasing levels of CO during the same period. It is worth mentioning the spatial distribution of cold and hot spots and the correlation between cold spots and the expansion of metro lines indicates the potential role of metro lines in decreased CO levels and improved air quality due to reduced vehicular emissions (Figure 7(a)).

Similarly, the relative changes in SO₂ at district level during the period 2019-2025 were found to have a cold spot in the eastern and central parts of the city, overlapping with metro system coverage, especially the Blue and Green Lines. This emphasizes reduced SO₂ emissions (Figure 7(b)). The delineated cold spots involved 120 and 39 districts of Riyadh city in the case of CO and SO₂ and accommodated 49.6% and 29.6% of the total city population, respectively.



(a)



(b)

Figure 7. Hot spot analysis of changes in CO and SO₂ concentration in Riyadh city between 2019 and 2025.

Generally, hot spot analysis provides clear spatial insights into how urban infrastructure, particularly the metro network, influences air pollution patterns, where central districts of Riyadh have consistent improvements in both CO and

SO₂, likely due to enhanced public transportation and urban planning. Also, among all metro lines green, blue, and purple lines appear strongly correlated with air quality improvement in CO and SO₂ levels.

These findings provide insights into the relationship between urban transportation infrastructure and air quality improvement in Riyadh city, the robustness of these findings has some limitations that future studies need to address. One of these limitations is the temporal scope of the analysis, which focuses on relatively short pre- and post-implementation periods (January-March 2019 and January-March 2025), potentially overlooking seasonal variations and longer-term trends in air quality. Moreover, the study does not consider other concurrent urban development [projects that may influence air quality in the city. Accordingly, future research work is needed to incorporate longer timeframes and consider broader environmental factors to enhance the robustness of findings.

4. Conclusion

The temporal analysis of air quality parameters in Riyadh city between 2019 and 2025 reveals different trends. In this respect, it was noted that the Ultraviolet Aerosol Index (UVAI) showed a clear increase, particularly in central urban areas and along major metro lines, pointing to a rising concentration of aerosols such as dust or pollution that may be due to both urban development and natural factors. On the contrary, improvements in carbon monoxide (CO) and sulfur dioxide (SO₂) levels were observed during the period 2019-2025 across some districts of Riyadh city, particularly those intersected by the Riyadh Metro lines. These reductions highlight the vital role of the metro system in mitigating vehicular emissions and enhancing air quality in the city. Spatial analyses confirmed the random distribution of relative changes in aerosol and the significant clustering of improved CO and SO₂ concentrations in metro-served areas. Generally, the clear reductions in CO and SO₂ highlight the positive environmental impact of sustainable public transport initiatives in Riyadh.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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